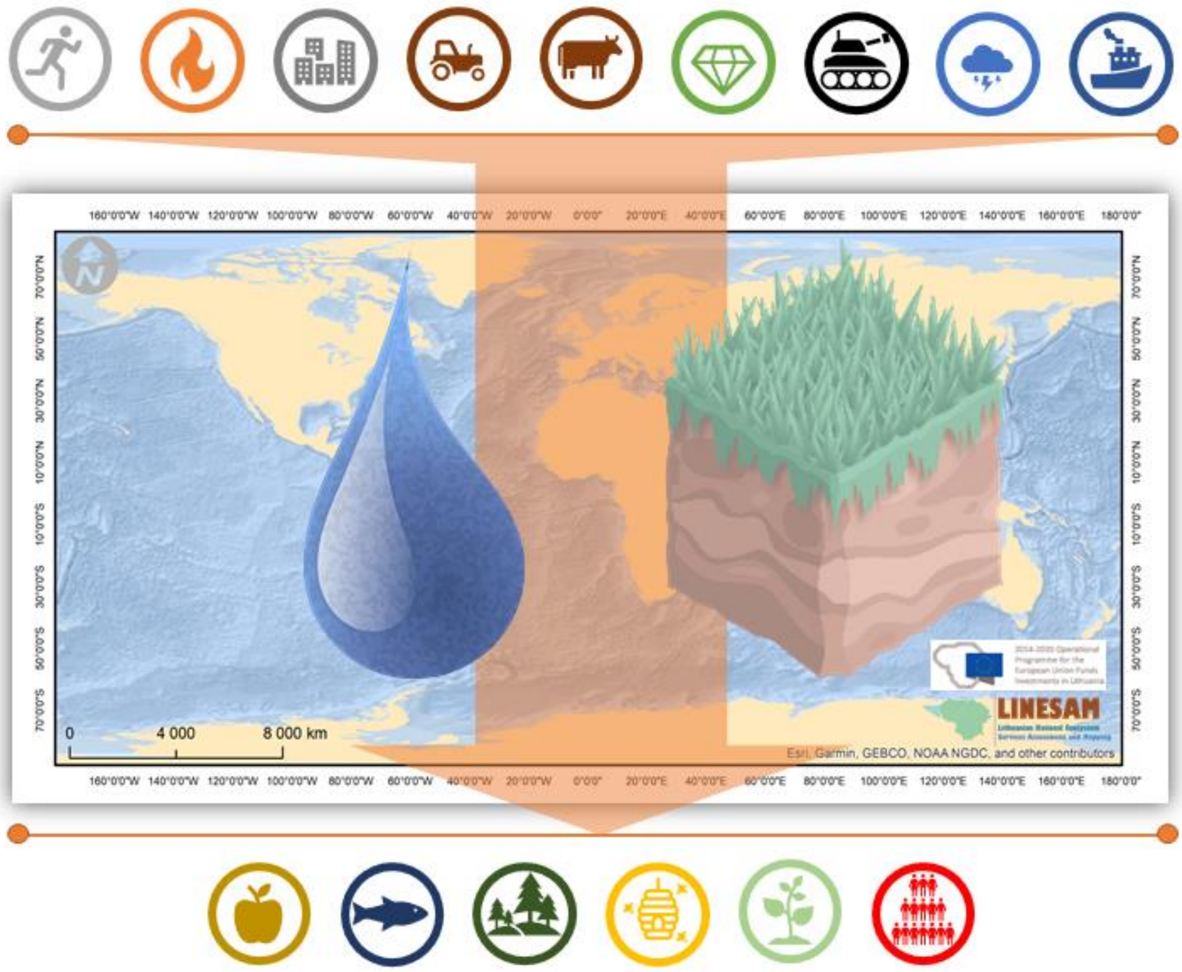
Graphical Abstract



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Soil and water threats in a changing environment

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Background

A fast pacing climate change exacerbates the multitude of human impacts. Several reports highlighted (e.g., **Magurran, 2016; Lewis et al. 2017; Diffenbaugh et al., 2018**) that the degree of impact imposed by human activities on all the ecosystem components are unprecedented. We entered a new era, the Anthropocene (**Malhi, 2017; Laurence, 2019**). In this new area, soil and water resources are exposed to tremendous pressure, and our life depends on it.

Soils and water environments (e.g., freshwater, coastal and marine) provide a wide range of direct and indirect regulating (e.g., carbon sequestration, climate regulation, water purification and storage, flood retention), provisioning (e.g., food, fiber, wood), and cultural (e.g., education, recreation aesthetic) ecosystem services (ES). Therefore, both soils and water are the key elements to humankind (**Barbier, 2017; Pereira et al., 2018; Jorda-Capdevila et al., 2019**). Soils interact in a continuum through very complex processes and feedbacks. The agriculture practices have implications on land degradation, water bodies eutrophication and pollution, coastal floods and soil salinization.

Here, we present numerous studies focusing on how land abandonment (**Tarolli et al., 2019**), urbanization (**Ferreira et al., 2018**), agriculture intensification (**Panagos et al., 2016**), mining (**Zibret et al., 2018**), warfare activities in relation to land degradation (**Certini et al., 2013**) and climate change (**Plaza et al., 2019**) are accelerating soil and water resources degradation, and reducing their capacity to provide ES in quality and quantity. These drivers of change either interact individually or coupled at different spatio-temporal scales.

Land abandonment

Land abandonment is an environmental, socio-economic, and political process, which changes the rural landscapes in a radical way and affects both developing and developed countries a (**Li and Li, 2017**). Land abandonment became more evident since the 1950s and can be attributed to industrialisation, harsh conditions for agriculture practices, remoteness, depopulation, and non-favorable economic conditions in rural areas (**Perpina-Castillo et al., 2018**). Depending on local factors, agro-climatic conditions, or conservation status, land abandonment can be considered positive (e.g., increase soil fertility, carbon sequestration), negative (e.g., increase soil erosion and wildfire risk) or variable (e.g., biodiversity) (Ustaoglu and Collier, 2018). Globally, it is estimated that between 1700 and 1992, 1.47 million km^2 has been abandoned (Ramankutty and Foley, 1999). In Europe, several areas have been abandoned (Renwick et al., 2013). Feranec et al. (2010) found that between 1990 and 2000 (25 European countries) that approximately 88,000 km^2 has been abandoned. Literature findings report the land abandonment trends in Bulgaria, Albania, Croatia, Greece (Zakkak et al., 2015), Netherlands, Germany, Belgium, Austria (Prevosto et al., 2011), Spain (Romero-Diaz et al., 2017), Portugal (van der Zanden et al., 2018), Poland (Sanderson et al., 2013), United Kingdom (Ford et al., 2012), France (Foucher et al., 2019), Italy (Brandolini et al., 2018), Switzerland (Rusterholz et al., 2019), Hungary (Cegielska et al., 2018), Baltic (Nikodemus et al., 2005) and Scandinavian countries (Rautiainen et al., 2016). Approximately 11% agricultural area of the European Union (EU) is in risk of land abandonment till 2030 (Perpina-Castillo et al., 2018). Land abandonment causes limited management of vegetation in semi-natural areas. Several landscapes are affected by a rewilding process that further degrades agricultural terraces (Tarolli et al., 2019), increases evapotranspiration (Wang et al., 2018a) and decreases the water quantity reaching to water bodies (Khorchani et al., 2020). Vegetation encroachment is also one of the causes of the increasing severity of summer wildfires in the Mediterranean (Moreira et al., 2020). However, as we assist in recent years, these wildfires also affect other parts of Europe, such as Scandinavia (Bodin and Nohrstedt, 2016). These events have an impact on soil degradation, especially if the recurrence is high (Mayor et al., 2016). After a wildfire, the removal of vegetation and soil cover increases ash and soil transport to water bodies (Nunes et al., 2018; Rhoades et al., 2019). After the wildfires, the first rainfalls erode the bare soil and transport elements (e.g. nitrogen, phosphorous, heavy metals, and polycyclic aromatic hydrocarbons) that decrease the freshwater quality. In many cases, water for human consumption is affected as well (Smith et al., 2011; Martin, 2016).

Urbanization

It is expected that by 2050, 68% of the population lives in cities (United Nations, Department of Economic and Social Affairs, Population Division, 2019), and this will impose high pressure on urban and peri-urban areas (e.g., land consumption for water demand). Urbanization is a process connected with land abandonment, increases the asymmetries in the landscape and accelerates socio-economic problems such as poverty, housing prices, unemployment, crime, and urban sprawl (Zhang, 2016). Urban sprawl is one of the most important causes of land consumption and soil degradation. It is a global phenomenon and increases soil sealing, pollution, compaction, and erosion (Hu et al., 2001). When soil is sealed, vital soil functions are lost or dramatically restricted (e.g., water infiltration, carbon storage) (Scalenghe and Marsan, 2009). In addition, soil sealing substantially increases the risk of floods, urban heat island, pollutant transport and contamination of water resources (Pistocchi et al., 2015; Vanderhaegen et al., 2015; Fokaides et al., 2016). At the end, fertile agriculture soils are also lost declining the capacity for food provisioning in areas close to cities (Dadi et al., 2016; Dupras et al., 2016). This is especially visible in Africa (Radwan et al., 2019) and Asia (Peerzado et al., 2019), where food security is under threat. Since 1950's, it has been observed a growth of 78% of the sealed surface in the EU, while the population increased only 33%.[1] This phenomenon was observed in several European cities (Naumann et al., 2018) such as Paris (Raimbault, 2019), Amsterdam (Korthals Altes, 2019), Barcelona (Salvati and Carlucci, 2016), London (Paul, 2017), Berlin (Lauf et al., 2106), Montpellier, Rome (Perrin et al., 2018), Milan (Canedoli et al., 2018), Lisbon (Mascarenhas et al., 2019), Athens (Gounaridis et al., 2018) and Budapest (Kovács et al., 2019). In EU countries, this is very likely attributed to the increase of tourism, second residence, and the infrastructures associated with this expansion (e.g., roads, railways, airports, etc.) (Morote and Hernandez, 2016; Cuadrado-Ciuraneta et al., 2017). In developing countries, urban sprawl is attributed to rural exodus triggered by malnutrition, hunger, and food insecurity (Abu Hatab et al., 2019).

Traffic, construction sites, gasoline stations, energy production, military camps, industrial activities (Fazeli et al., 2019), bonfires (Dao et al., 2012), and waste (He et al., 2017) are responsible for soil, surface and groundwater pollution. In Europe, a recent inventory recorded 340,000 contaminated sites and 2.5 million potentially contaminated ones (Panagos et al., 2013). Soil pollution reduces drastically the capacity of soils to provide ES such as soil biodiversity and plant growth. In addition, food produced in contaminated soils is unsafe for human and animal consumption (Rodríguez-Eugenio et al., 2018). Nevertheless, as highlighted in the revision carried out by Morel et al. (2015), urban soils are still able to provide some ES (e.g., runoff and flood control, air purification), mainly the ones that have a lower anthropogenic impact (vegetated pseudo-natural). The exposition of human contamination by food ingestion and dermal contact is increasing as a consequence of the urban agriculture and revitalization of brownfields. Several works have been carried out about the potential threats imposed by urban agriculture. Some highlighted the risks for human health (e.g., Branchet et al., 2018 Lopez et al., 2019), while others have concluded the contrary (e.g., Boente et al., 2017; Margenat et al., 2019). Despite the uncertainties, urban agriculture has been suggested as a practice that reduces the circular economy and carbon footprint (Wang et al., 2018b; Hu et al., 2019). In the same line of urban agriculture, soils in brownfields are known to be highly contaminated (Song et al., 2019), and some alternatives are being carried out such as the construction of urban parks (Cundy et al., 2016; De Valck et al., 2019). Nevertheless, these measures can be questionable since some of these sites are highly contaminated and may increase the exposition of the visitors to heavy metals and other pollutants.

In dense urban areas, if soils are not sealed, they are affected by compaction in unpaved urban trails and roads and green areas management (Ng et al., 2018a) (Figure 1). In cities, soil compaction is a consequence of traffic and heavy machinery circulation. In these areas, soil biodiversity, water storage, and infiltration are strongly reduced (Ferreira et al., 2018). As in the case of soil sealing, compaction increases the risk of floods and the exposition of the population to extreme rainfall events (Gregory et al., 2006; Umer et al., 2019). The reduced soil infiltration and the availability of sediments in unpaved

[1] https://ec.europa.eu/environment/soil/sealing_guidelines.htm

roads increase soil erosion rates (Figure 1). Several works observed high erosion rates and gully formation in unpaved roads (Gudino-Elizondo et al., 2018; Tanigushi et al., 2018; Wemple et al., 2018). Wind erosion is also a problem in urban bare soil areas. These areas are an essential source of particulates (e.g., $PM_{2.5}$ and PM_{10}) (Luo et al., 2011), pollutants (Harada et al., 2019), and microplastics (Horton and Dixon, 2018). The suspension of these elements has impacts on human health, e.g., respiratory diseases (Garcia et al., 2014) and the accumulation of pollutants in the blood (Laidlaw and Filippelli, 2008).

Catchments with sealed, polluted, and compacted soils in heavily urbanized areas are a source of a wide range of pollutants (McGrane et al., 2016; Salerno et al., 2018). It has been reported that high amounts of heavy metals, emerging pollutants (e.g. pharmaceuticals, household & personal care products, pesticides, industrial chemicals) and microplastics were detected in water bodies located near urban areas located in Asia - China (Yang et al., 2017; Luo et al., 2019); India (Sruthy and Ramasamy, 2017), – America - Brazil (Andrade et al., 2019), the USA (Sutton et al., 2016; Huerta et al., 2018), Canada (Crew et al., 2020); Argentina (Ame et al., 2019) – Europe (Zhou et al., 2019) – Spain (Celic et al., 2019; Schirinzi et al., 2019); United Kingdom (Burns et al., 2018); Ukraine (Vystavna et al., 2018); Greece (Mandaric et al., 2019); France (Aminot et al., 2016; Thiebault et al., 2017); Portugal (Pereira et al., 2017); Czech Republic (Grabicová et al., 2020); Sweden (Lindim et al., 2019) – Africa (Fekadu et al., 2019) – South Africa (Agunbiade and Moodley, 2015) - and - Oceania - Australia (Su et al., 2019). Therefore, this is a global problem. The concentration of heavy metals, emerging pollutants and microplastics in water poses important risks to wildlife and human health. A substantial number of works highlighted the contamination of fish and other sea animals with heavy metals (e.g., Bosch et al., 2016), emerging pollutants (e.g., Rocha et al., 2018) and with microplastics inside their stomach (e.g., Vendel et al., 2017).

Agriculture intensification

The population rise and changing consumption habits are increasing food demand dramatically (OECD/FAO, 2019). To feed a population of 9.6 billion in 2050, we need to produce 70% more food than we do today[2]. On the other hand, other reports highlighted that if we changed our consumption habits profoundly (e.g., reducing meat and dairy products consumption), the food that we produce today would be enough to feed the population in 2050 (Berners-Lee et al., 2018). Agriculture production is expected to increase in the next decade by 15%, although agricultural area remains the same (OECD/FAO, 2019). This implies high pressure on soils to produce food which will accelerate land degradation. Agriculture intensification is already degrading our soils and decreasing the long-term capacity to produce food. This is especially relevant since soils produce approximately 99% of our food (Kopittke et al., 2019). To reduce the impacts of agricultural intensification, several works proposed a "sustainable" (e.g., Jayne et al., 2019; Kropp et al., 2019) or "smart" agriculture intensification (e.g.,

[2] https://news.un.org/en/story/2013/12/456912

Govers et al., 2017; Gil et al., 2018), that may bring socio-economic (e.g., labour-saving practices, fertilizer, and water use) and environmental (e.g., water conservation, biodiversity, carbon storage, reduce pollution and greenhouse gases emissions) benefits. Sustainable agriculture intensification is considered a vital alternative to reduce the impacts on the environment and achieve food security (Thomson et al., 2019). Nevertheless, this concept needs more clarity about the practices and is being contested (Struik and Kuyper, 2017).

Agriculture intensification is associated with the increasing use of resources, industrial livestock production, plantations, use of heavy machinery (soil compaction and erosion), acidification, irrigation (soil salinization), water consumption, use and overuse of herbicides, pesticides and fertilizers, plastics, Livestock is increasing in order to meet the demand for meat and dairy products. Currently, livestock and agricultural use for feeding livestock occupies 70% of the arable land. The food produced by 1/3 of the global cropland is used for livestock consumption. In addition, the livestock industry is a high consumer of water, energy, and the land. The expansion of livestock farms is responsible for deforestation and loss of biodiversity (Dettenmaier et al., 2017; Willers et al., 2017; Van Zanten et al., 2018). A recent example of livestock expansion is the deforestation of Amazonia (Leao Pereira et al., 2020). Despite the negative impacts related to livestock production, in some grassland ecosystems, extensive grazing contributes to biodiversity (e.g., Moinardeau et al., 2016; Enri et al., 2017). The impact of livestock on soil properties depend on grazing intensity and the climatic zone (Abdalla et al., 2018). In intensively grazed ecosystems, there are negative effects on soil properties because of the high livestock density. In such conditions, grazing increases soil compaction, eliminates cover protection and reduces key soil properties such as pH, electrical conductivity (Zhang et al., 2017), organic carbon, nitrogen (Byrnes et al., 2017), root biomass (Wang et al., 2017) and hydraulic conductivity (Vandanorj et al., 2017). Also, the use of veterinary antibiotics in cattle increases the content of these elements in the soil via animal droppings (Tasho and Cho, 2017). The increase of soil compaction increases overland flow, nutrient and sediment transport, especially where grazing is more intense (Chen et al., 2017a; Mayerhofer et al., 2017; Pulido et al., 2018). In addition, the presence of bare soil areas in highly grazed areas may increase wind erosion potential (Shaver et al., 2018).

Recent increase of industrial plantations are responsible for biodiversity degradation, and soil nutrients reduction as those crops replaced natural land uses (e.g., forests, grasslands) (Lutter et al., 2016; Castano-Villa et al., 2019; Wang et al., 2019). The effect of these plantations on wildfire severity is a matter of discussion. Some studies highlighted that there is a decrease (Fernandes et al., 2019), others an increase (Ndalila et al., 2018). Key soil properties such as organic carbon, cation exchange capacity, nitrogen, calcium, and microbial biomass were found to be lower in Eucalyptus plantation compared to grasslands (Temesgen et al., 2016). The plantation of hybrid poplar and willow also induce important changes in the fungal and bacterial community (Xue et al., 2016). Some works identified that carbon stocks are higher in soils covered by native vegetation, compared to plantations (Chen et al., 2017b; He et al., 2018a). For management purposes and increased carbon sequestration, natural succession is more beneficial than short rotation plantations (**Kalt et al., 2019**). The impact on soil properties depends on the rotation time. In Eucalyptus plantations, rotation periods lower than ten years affect soil quality importantly (**Xu et al., 2020**). Despite the degradation observed after the establishment of short rotation industrial plantations, when the soils are amended and irrigated, soil fertility and quality are improved (**e.g., Madejon et al., 2016; Moreno et al., 2017**). When compared with croplands, the soil quality of short-rotation plantations is higher because of the low disturbance and mineralization rate, and positive trends in soil organic carbon are observed (**Georgiadis et al., 2017; Zheng et al., 2017**). In addition, carbon dioxide emissions are lower (**Ferre and Comolli, 2018**). Heavy mechanization is a usual practice in short-rotation plantations (**Vanbeveren et al., 2017**). Nevertheless, they are more frequent in croplands managed intensively, and this has negative implications on soil quality.

The use of machinery in agriculture is associated with high levels of compaction and decline of soil functions (e.g., water infiltration, nutrient cycling biological activity, habitats for organisms) and ES provision (**Keller et al., 2019**). In Europe, approximately 33 million ha are compacted as a consequence of heavy machinery traffic (**FAO, 2015**). Soil compaction in agricultural areas decreases soil water content and infiltration, aggregate stability, porosity, carbon sequestration, nutrient content, biological diversity, and agriculture productivity. On the other hand, it increases bulk density, carbon dioxide emissions, and erosion (**Lipiec and Stępniewski, 1995; Nawas et al., 2013; Cid et al., 2014; Beylich et al., 2010; Shah et al., 2017**).

Erosion is the major threat to soils globally. The loss of topsoil reduces the capacity of the soil to store water, and the space for root development, decreasing soil productivity (**FAO, 2015**). Various studies existed for global soil erosion rates and it was estimated that about 20–30 Gt of soil is lost per year (**FAO, 2015**). A recent study carried out by **Borrelli et al. (2017a)** found that in 2001 the soil loss by water erosion was 35 pg yr^{-1} increasing to 35.9 pg yr^{-1} as a consequence of land-use change (**Figure 2a and b**). Wind erosion is also very much uncertain, but it is predicted that 2 Gt yr^{-1} is eroded from arable lands while in European Union this amount is about 53 Mg yr^{-1} (**Borrelli et al., 2017b**). The rate of topsoil erosion in agricultural areas is much higher than the soil formation rate (bellow 1 tonnes ha^{-1} yr^{-1}). This represents a high risk of permanently losing a non-renewable resource such as soil. Soil erosion has dramatic impacts on agriculture because of the loss of nutrients that can only be replaced by the application of fertilizers (**Panagos et al., 2018**).

The widespread industrial farms increased the number of pesticides, herbicides, and fertilizers in the soil to increase productivity. The intense use of copper as herbicide in vineyards and permanent crops during last century increased the copper concentration in those land uses (**Ballabio et al., 2018**). Pesticides are the base of agriculture intensification, and the soil contamination associated with pesticides application is a global issue (**Silva et al., 2019**). Several studies found that the use of pesticides changes severely soil physical properties (e.g., texture), soil microbiology, and productivity both in the farms where applied but in the surrounding ones as well. The concentration of pesticides decreases food quality and affect negatively human health (Mandall et al., 2020; Singh et al., 2020). For example, some studies showed that glyphosate herbicide is probably cancerogenic (Zoller et al., 2018; Centner et al., 2019). Recently, several studies highlighted also the presence of pharmaceutical components in soils (Less et al., 2016; Li et al., 2019) and irrigated water (Biel-Maeso et al., 2018; Pico et al., 2020), contributing to the loss of soil functions and fertility.

Other evidence of agriculture intensification is the use of plastics in agriculture. This activity is responsible for the increase of world plastic consumption (Pazienza and De Lucia, 2020). It is estimated that 63,000–430,000 of microplastic are added to soils in Europe. In the USA, the range of microplastic added to soils varies between 44,000 and 300,000 tons annually. It is very likely also that soils are a larger reservoir of microplastic compared to the oceans (Hurley and Nizzeto, 2018). The most important sources of plastics/microplastics in agroecosystems are coatings, applications, waterborne paints, electronics, adhesives, and medical applications, mulching film, wastewater and sludge irrigation (He et al., 2018b; Ng et al., 2018b; Pico et al., 2020). Plastic is an important form of soil pollution, even though few works were carried out (Chae and An, 2018). The available results show that the use of biodegradable plastic at short term do not have detrimental impacts on soil properties and functions (Sintim et al., 2019). However, others show that microplastics in soil increase pollution by leaching and reduce water content quality as they are transported by bioturbation and plowing (Rillig et al., 2017; Hurley and Nizzeto, 2018; Wan et al., 2019) affecting also groundwater (Re, 2019). In addition, microplastics can enter the food chain by invertebrates and other animals (Ng et al., 2018b; Selonen et al., 2020). Since intensively agricultural areas are more susceptible to water and wind erosion (Panagos et al., 2016), they are potentially a source of microplastics which are transported to other areas by water and wind, affecting human health (Hurley and Nizzeto, 2018; Rezeai et al., 2019). Microplastics may have potential effects on plant composition since plastic films increase water evaporation and reduce microbial diversity (Rillig et al., 2019).

Intensive agriculture practices consume a high amount of water. This high consumption is linked to the high demand of water for crop production and livestock management. The growing demand for food and the frequency of drought periods will increase water scarcity, social conflicts, and land degradation. In 2090, it is expected that the expansion of irrigated areas is responsible for 70% of water consumption (FAO, 2017; Huang et al., 2019). The land occupied by irrigated arable land corresponds to 20% of the total cultivated area. However, it produces only 40% of the food[3]. Intensive agriculture is contributing drastically to the reduction of surface and groundwater resources (Figure 3). There is evidence about this serious threat in several parts of Asia – Iran (Hashemy Shahdany et al., 2018), India (Thakur et al., 2016), China (Zhong et al., 2019) and Saudi Arabia (Youssef et al., 2020); Africa – Algeria (Khezzani and Bouchemal, 2018), Libya (Alfarrah and Walraevens, 2018) and Morocco (Malki et

[3] https://www.worldbank.org/en/topic/water-in-agriculture

al., 2017); Mediterranean Europe – Spain (Rupérez-Moreno et al., 2017); America – Peru (Schwarz and Mathijs, 2017) and Mexico (Wurl et al., 2018), to name some.

The use and abuse of water in intensive agriculture are a cause of soil salinization and sodification. It is estimated that 1 billion ha of soil is affected by salinization. Soil salinization is a natural process of semi-arid areas, where evapotranspiration is higher than precipitation, leading to the accumulation of salts. The natural causes of soil salinity are atmospheric deposition, rock weathering, and saltwater intrusion. The anthropogenic sources to salinization are: irrigation during long periods, inadequate drainage facilities that increase the rise of groundwater level, use of brackish water, plantations with shallow roots (increase the rise of saline groundwater), and saltwater intrusion in coastal areas (as a consequence of high withdrawal of groundwater). Soil salinity and sodification is a world-wide problem affecting several countries. Big parts in China, Pakistan, India, The USA, Kazakhstan (Figure 4), Egypt, and Iraq are affected by salinization (FAO, 2015). Salinization has undesirable effects on soil properties such as a decrease of fertility, soil organic carbon stocks, aggregate stability, and microbial activity. Also, it increases the dispersion of clay particles, availability of heavy metals, greenhouse gas emission, runoff, and erosion (Dang et al., 2016; Daliakopoulos et al., 2016; Raiesi and Sadeghi, 2019). Several works show that salinization decreases dramatically crop productivity (e.g., Butcher et al., 2016; Majeed and Muhammad, 2019; Etesami and Noori, 2019). It is expected that climate change will increase soil salinization as many areas will be affected by the sea level rise. One of the most typical examples is in Bangladesh (Dasgupta et al., 2015). However, this is evident as well in other areas of the globe, such as Europe (Daliakopoulos et al., 2016). A warmer climate will result in the expansion of the areas with salinization risk (e.g., Mediterranean). In addition, the increase of irrigated areas because of the population growth and the consequent demand for food is expected to increase the areas affected by soil salinization (Butcher et al., 2016; Siegel, 2016; Daliakopoulos et al., 2016). Concluding, the combination of groundwater overexploitation, warmer climate, and sea-level rise will increase soil salinity.

The areas affected by intensive agriculture are an important source of pollutants transport to freshwater and marine ecosystems. In catchments with high agriculture land use, there is a degradation of surface and water quality (e.g., eutrophication), and a loss of biodiversity because of agrochemicals use. Climate change can exacerbate these impacts (e.g., Foster and Custodio, 2019). Examples of those effects are observed in several European countries such as France (Bayramoglu et al., 2020), Spain (Pardo e al., 2018), Portugal (Palma et al., 2018), Italy (Pastorino et al., 2019), Germany (Brettschneider et al., 2019), Greece (Kourgialas et al., 2017); Asia – Turkey (Şener et al., 2017), Iran (Solgi et al., 2018), India (Irshad Rather et al., 2016), South Korea (Park et al., 2018); Africa (Hess et al., 2016) – Ethiopia (Teklu et al., 2018), Rwanda (Uwimana et al., 2017), Algeria (Bouaroudj et al., 2019) and America-Mexico (Redon-von Osten and Dzul-Caamal, 2017), Costa Rica (Fournier et al., 2018), Ecuador (Damanik-Ambarita et al., 2016) and the USA (Motew et al., 2017). The use of plastics in modern agriculture also increased the presence of these substances in water bodies (e.g., Horton et al., 2017). The transport of these pollutants to coastal and marine areas is the cause of the increase fish contamination (Olsvik et al., 2019), but also for the development of algae blooms in coastal areas (Le Moal et al., 2019). This is particularly important in small seas such as the Baltic, where frequently is observed large hypoxic zones (Andersen et al., 2017).

Mining

Mining deposits are high in South Africa, Andean region, Western of the USA and Mexico, the Mediterranean coast of Africa, and Central Asia (Figure 5). In 2017, 17.2 billion metric tons of minerals were extracted from mines. Russia, China, the USA, and Australia are the countries with highest mining activity worldwide where this sector is also important for the economy. Asia is by far the continent where the exploitation is high, followed by North America, Europe, Oceania, Latin America, and Africa (Reichl and Schatz, 2019). In Europe, there are approximately 19 000 enterprises related to mining that employ 515 000 persons (Eurostat[4]). However, this industry is tied to dramatic environmental degradation. Mining activities degrade soils in several regions of the world– Bulgaria (Simeonova et al., 2018), Italy (D'Orazio et al., 2020), Poland (Ciarkowska, 2017) and Spain (Romero-Baena et al., 2018); Asia – India (Pandey et al., 2019), China (Dejun et al., 2016), Philippines (Martinez et al., 2018), Russia (Pietron et al., 2017), Saudi Arabia (El-Taher et al., 2016), Mongolia (Timofeev et al., 2016), Iran (Moore et al., 2016) and Armenia (Tepanosyan et al., 2018); Africa – Niger (Dan-Badjo et al., 2019), Ethiopia (Meaza et al., 2017), Republic of Congo (Pourret et al., 2016), Namibia (Kříbek et al., 2018) and Mali (Bokar et al., 2020); America – Colombia (González-Martínez et al., 2019), Brazil (Silva et al., 2018); French Guiana (Guédron et al., 2018); Oceania – Australia (Wang et al., 2020), just to mention some.

The impacts of mining include excavation, stripping, dumping, and transportation and have different impacts on soil physical, chemical, and biological properties (Feng et al., 2019). Mining activities involve the construction of roads and the high circulation of trucks increasing soil compaction and reduction of soil porosity, aggregate stability, field capacity, water infiltration and soil organic matter (Ahirwal and Maiti, 2016; Dejun et al., 2016; Wang et al., 2017; Jing et al., 2020). Some studies correlate mining activities with an increase in soil pH and electrical conductivity (Ahirwal and Maiti, 2016), while others a decrease (Pandey et al., 2019). A reduction of essential elements for plants such as nitrogen and phosphorus were identified as well close to mining activities (Jing et al., 2018; Pandey et al., 2019).

Most of the studies relevant to mines focus on heavy metal pollution. Mining activities increase the concentration of toxic metals importantly on soils (e.g., Arsenic, Aluminium, Cobalt, Cadmium, Copper, Lead, Mercury, Iron, Manganese, Zinc, Chromium, Nickel among others) (e.g., Diami et al., 2016; Musilova et al., 2016; Xiao et al., 2017; Tepanosyan et al., 2018). Because of the soil degradation and

[4] https://ec.europa.eu/eurostat/statistics-explained/index.php?title

the increase of toxicity, microbiology is severely affected. Several studies highlighted a decrease in microbiology richness, diversity (**Rosenfeld et al., 2018; Sanchez-Castro et al., 2017**), composition (**Martinez et al., 2018**), and biomass (**Narendrula-Kotha and Nkongolo, 2017**). The impacts on soil properties can persist in time and, in some cases, can be detected 20 years after mine closure (**Sołek-Podwika et al., 2016**). Mining activities involve vegetation removal and increase the water erosion (**Karan et al., 2019**) and wind erosion (**Pietron et al., 2017**) in the exploited areas, and the contamination of soils and water resources in the nearby regions (**Pandey et al., 2016; Chakraborty et al., 2017; Liu et al., 2019**). High levels of toxic elements were observed in soils and vegetables planted in the vicinity of mining areas, increasing the residents and the end consumers' health risk (**Bui et al., 2016; Antoniadis et al., 2017**).

Mining reduces groundwater quality drastically (**Tiwari et al., 2016**) and increases fresh (**Johnson et al., 2019**) and marine water degradation (**Chen et al., 2017c**). In the period 2007-2017, there were recorded 38 accidents related to mine tailing's accidents. From these, 11 were considered extremely damaging for the environment provoking each of them ≥ 1 000 000 m^3 total discharge of fine tailings. One of the latest accidents (Fundao dam in Brazil), discharged 33 million m^3 of Iron ore tailing slurry in freshwater ecosystems. This was considered the worst environmental disaster in the mining industry (**Carmo et al., 2017; United Nations, 2017**). In the last 20 years, the number of accidents related to the tailings dam's failure doubled. Evidence of massive freshwater resource degradation caused by these accidents was observed in Spain (Aznalcóllar and Los Frailes), Brazil (Fundao and Brumadinho), and Canada (Mt Polley) (**Meharg et al., 1999; Amstrong et al., 2019**). Runoff from mining areas augments the amount of dissolved heavy metals, turbidity, suspended particulate matter, pH, hardness, and sulfates in water bodies, increasing the degradation of zooplankton and phytoplankton communities, affecting the trophic chain drastically. These impacts can be persistent in time and be evident even after mine decommission (**Garcia-Ordiales et al., 2016; Zipper et al., 2016; Leppanen et al., 2017; Cordeiro et al., 2019**). Several mine tailing disasters were reported to reach the ocean, as in Fundao (Brazil) (**Carmo et al., 2017**), decreasing the abundance, density, and richness of marine benthic communities (**Matthews-Cascon et al., 2018**). Marine offshore oil exploitations also have dramatic impacts on marine water quality, discharging hazardous substances such as aromatic hydrocarbons, heavy metals, and other components used for oil production (**Carpenter, 2019**). Physical impacts in marine wildlife biocenoses can be extended to 0.5 to 1 km. Toxic elements concentration can be detected in a distance of 2 km from the mine while the high oil-contaminated cuttings disturbance in fauna are recorded even at 5 km distance (**Bakke et al., 2013**). Marine offshore infrastructures affect macrofauna, foraminifera (**Laroche et al., 2016**), coral reefs (**Nordborg et al., 2018**), microbial abundance, richness, and diversity negatively (**Potts et al., 2019**).

Warfare activities in relation to land degradation

War and warfare activities have a tremendous impact on the biosphere and induce strong and long-lasting impacts on ecosystems function and structure. They change the habitats profoundly, increase pollution, and contribute actively to the decline of biodiversity in terrestrial and aquatic ecosystems. For example, the war conflicts in Africa are one of the responsible for large mammals decrease in protected areas. Indirect impacts such as refugee's movement and settlements are also a cause of environmental degradation. However, in conditions where an area is classified as an "exclusion zone" (e.g., Korean Demilitarized Zone), the absence of human disturbance results in an increase of biodiversity (**Lawrence et al., 2015; Yoo et al., 2016; Daskin and Pringle, 2018; Rossi et al., 2019**).

War induced disturbances have important implications on soil physical, chemical, and biological properties. These impacts may remain for centuries after the war. Explosion provoked by bombs, mines or grenades (bombturbation), excavation of tunnels and trenches, infrastructure construction, and vehicle and troops circulation are an example of soil physical degradation (**Certini et al., 2013; FAO, 2015**). For example, bombturbation has the capacity to detach and remove a large amount of sediments, disturb and remix soil profile, and change landscape morphology. The impacts of bombturbation depend on the characteristics of the landscape affected (e.g., bedrock, relief, soil, and land use) frequency and type of explosives (**Ilyés, 2010; Hupy and Schaetzl, 2008; Hupy and Koehler, 2012**). Trenches and tunnel excavation also affect soil properties by destroying soil profile and remix soil horizons. Troops, vehicle circulation, and infrastructure development increases soil compaction and sealing, respectively. As a consequence of the intense soil disturbance and vegetation removal, several works highlighted the increase of soil erosion in areas affected by war activities (**Machlis and Hanson, 2008**) such as in Bosnia (**Tosic et al., 2012**), the USA (**Perkins et al., 2007**), Kuwait (**Al-Awadhi et al., 2005**) and more recently in Syria (**Abdo, 2018**), where war conflicts have been very intense in the last years (**Figure 6**). **Prose et al. (1985)** highlighted that trench excavation and tank tracks in the Mojave Desert military area were the most important drivers of soil erosion. The direct or indirect (e.g., refugees) impacts on soil degradation are especially severe in drylands as a consequence of the fragility of these ecosystems to human disturbance (**Rossi et al., 2019**). Warfare activities reduce soil infiltration, litter cover, organic matter, carbon, and nitrogen (**Trumbull et al., 1994; Whitecotton et al., 2000; Garten Jr. et al., 2003**).

A considerable body of research was carried out about the impacts of war and warfare activities on soil pollution, namely heavy metals, oil products, radioactive elements, organophosphorus nerve agents, nitroaromatic explosives, energetic materials and dioxins from herbicides (**Pitchel, 2012; Certini et al., 2013**). Examples come from Europe – Latvia (**Kokorite et al., 2008**), Lithuania (**Idzelis et al., 2006**), Poland (**Gebka et al., 2016**), Switzerland (**Robinson et al., 2008**), Croatia (**Vidosavljevic et al., 2013**), Serbia (**Radenkovic et al., 2008**), Czech Republic (**Sladkova et al., 2015**), Romania (**Petre et al., 2016**), Italy (**Siles and Margesin, 2018**), Portugal (**Matias et al., 2009**); America – Brazil (**Lima et al.,** 2011), Puerto Rico (Davies et al., 2007), Alaska (Busby et al., 2020) and the USA (Clausen et al., 2004) and Asia – Kuwait (Al-Awadhi et al., 2005) and Korea (Ahmad et al., 2012), to mention some. It has been widely reported that heavy metals such as Arsenic, Zinc, Lead, Mercury, Copper, Aluminium, Chromium, Titanium, Iron, Vanadium contaminate soils dramatically in areas affected by warfare activities (e.g., Hussain and Gondal, 2008; Ahmad et al., 2012; Gebka et al., 2016) as a consequence of the explosion of mines, bombs, grenades, or oil spill. They are also responsible for the increase of radiation (e.g., ^{238}Uranium, Potassium-40) in soil (e.g., Esposito et al., 2002; Mitrovic et al., 2016). In arid and semi-arid environments, the content of these elements in the soil decreases fast as a consequence of leaching and/or wind erosion (Salama et al., 2019). Organophosphorus nerve agents are considered the deadliest chemical warfare element (Vucinic et al., 2017) and have been identified in important amounts in soils affected by warfare activities (e.g., Gravett et al., 2013; Valdez et al., 2018). A similar situation has been observed in nitroaromatic explosives (e.g., Thomas et al., 2018; Kober et al., 2019) and energetic materials (Taylor et al., 2017). The impact of the release of warfare activities on soil biology is dramatic. Previous works highlighted that could destroy biological crusts (Kade and Warren, 2002), contaminate soil arthropod community (Migliorini et al., 2004), reduce nematode diversity (Althoff et al., 2007), enzymatic activity (Baran et al., 2004), earthworm abundance (Althoff and Thien, 2005), fungi and microbial biomass carbon (Meyers et al., 2007). It has also been reported that plants and crops that grow in areas affected by warfare activities have a high presence of heavy metals (Busby et al., 2020) and radioactive elements (Razaq et al., 2019) in their shoots and roots. Also, explosive compounds impact plants in their different life stages, with substantial implications on ecosystem processes (Via and Zinnert, 2016). Once in the soil, leaching and surface runoff will transport chemicals from warfare and war activities into water resources. Several studies observed that groundwater resources were contaminated with heavy metals (Bakir et al., 2003), polycyclic aromatic hydrocarbons (Petrula et al., 2018), bacteria's (Paukstys and Belickas, 1996), polyfluorinated alkyl substances (PFAS), film forming foam (AFFF) (Backe et al., 2013), explosive compounds (Spiegel et al., 2005) and aromatic aminocompounds (Preis et al., 1997). Pollutants from warfare areas were also found in rivers, lakes, and marine sediments (Idzelis et al., 2006; Gebka et al., 2016) and accumulated in fish tissues (Dvorak et al., 2020). Overall, warfare activities have severe ecological effects on terrestrial and aquatic ecosystems (Quist et al., 2003).

Climate change

Climate is likely the most important of the five soil formation factors (parent material, climate, organisms, topography and time) (Maher et al., 2003). Temperature and precipitation are key inputs to rock weathering, soil physical, chemical and biological activity and influence vegetation cover and erosional processes. Changes in climate affect soil resources importantly, and the ES provided. For example, the changes in precipitation influence water availability. The temperature will also be key in arid and semi-arid environments since it affects soil moisture and can increase salinization. With the increasing sea level rise, soils in coastal areas are vulnerable to salinization as well. Pedogenesis is also affected by climate change as it depends on water availability and temperature. High and low-temperature extremes affect microbiological activities. High temperatures also contribute to high carbon dioxide emissions (FAO, 2015)[5].

Changes in climate are part of earth history. The novelty in the recent climate change is unprecedented in the speed of change because of accelerated greenhouse gases emission. This new reality imposes extreme difficulties for ecosystems to adapt to a new climatic condition (IPCC, 2014). One of the most dramatic and evident impacts of climate change is permafrost degradation in polar, high altitude plateaus and mountain areas. Climate change scenarios predict a reduction extension, and this will affect the ecosystems and human infrastructures (Oliva and Fritz, 2018). Permafrost thawing is increasing the amount of greenhouse gas emission drastically to the atmosphere, as observed in Alaska, Canada, Sweden, Siberia (Anthony et al., 2016). This is also identified in altitude environments such as Tibetan Plateau (Mu et al., 2018) and Daxing'an Mountains (Gao et al., 2019). Permafrost thawing is accelerated with the increasing frequency of wildfires (Gibson et al., 2018). Permafrost degradation also triggers landslides (Patton et al., 2019), rockfalls (Magnin et al., 2017), mudflow (Stanilovskaya, 2018), dam-lakes (Haeberli et al., 2017) and human infrastructures such as buildings, settlements, roads, and railways (Hjort et al., 2018).

Climate change has severe impacts in agriculture production which is one of the most sensitive sectors of the economy. Climate change is a serious threat to food security since more frequent and intense extreme events, warmer temperatures, and water availability threaten the soil capacity to produce food. This is especially serious in developing countries (IPCC, 2014; FAO, 2016; Ciscar et al., 2018). The warmer temperatures are expected to decrease crop yields (maize, rice, wheat, and soy) in a drastic way (Moore et al., 2017). Soil stores more carbon than the atmosphere and terrestrial vegetation together (FAO, 2015). Despite the different numbers obtained in the literature, it is estimated that soil stores approximately 1500 pentagrams of carbon. The higher carbon stocks in soil and subsoil are stored in cold temperate moist and boreal moist environments (Scharlemann et al., 2014). Soils are a significant carbon sink; however, in agroecosystems, this capacity depends primarily on the management practices applied. Sustainable agriculture practices such as cover crops, plant residues and maintenance of grasslands contribute to soil carbon sequestration (Lugato et al., 2014). On the contrary, intensive agriculture areas increases the greenhouse gases emission contributing to climate change (e.g., Tian et al., 2016; Abbas et al., 2017; Zomer et al., 2017).

Climate change is expected to decrease surface and groundwater resources, especially in subtropical regions. Also, the frequency and intensity of floods and droughts will likely increase. There is also a high probability of the decrease of water quality, with implications to the drinking water supply. Climate change is recognized as a severe threat to water security. The melting of glaciers and permafrost will change the seasonality of freshwater streamflow’s and will increase the flux of sweetwater into the

[5] https://www.eea.europa.eu/signals/signals-2019-content-list/articles/soil-land-and-climate-change

oceans (**IPCC, 2014**)[6]. The change in temperatures and water regimes implies a modification in several other aspects such as groundwater recharge, runoff, evaporation, and water temperature. This will affect physical (e.g., ice cover, temperature, flow, stratification), chemical (e.g., oxygen content, colour, nutrient concentration) and biological (e.g., microbes in water, invasive species, species physiology, abundance, and diversity) water bodies condition (**Poesch et al., 2016; Mujere and Moyce, 2018; Denley et al., 2019**). In marine environments, the flux of freshwater is contributing critically to sea-level rise. In the period 2002-2005, Greenland and Antarctica had an ice mass loss of 265 ± 25 GT/year and 95 ± 50 GT/year, respectively. This corresponds to 0.72 (Greenland) and 0.26 (Antarctica) mm/year average global sea-level change (**Forsberg et al., 017**). In addition, the increase of freshwater in oceans is weakening the Atlantic overturning circulation and this may have feedback in climate north Atlantic climate dynamics (**Rainsley et al., 2018; Golledge et al., 2019**) as it happened in the past. Marine ecosystems will react heterogeneously to climate change. It is expected that climate change will shift ocean circulation, salinity, temperature, light, nutrients, carbon dioxide, and oxygen. Warming will affect the organism's physiology, species migration, and abundance. The increasing concentration of carbon dioxide will enhance ocean acidification and affect marine ecosystems. In addition, oxygen depletion is increasing the number of dead zones, particularly when coupled with other pressures, as eutrophication. Finally, climate change intensifies the upwelling regime that, on some coasts, can increase productivity. Nevertheless, it can also increase acidification and hypoxia (**Pörtner et al., 2014**).

Special issue contributions

Soil and water resources are exposed to multiple threats imposed by land use and climate change. In total manuscripts 12 were published from different parts of the world, including the Middle East, Africa, South America, Europe, Antarctica, China, and Siberia. The published articles were focused on permafrost thermal regimen (**Hrbáček et al., 2020-in this issue**) and impact on greenhouse emissions (**Masyagina and Menyailo, 2020-in this issue**). Other works studied the impacts of fires on greenhouse gases in boreal environments (**Ribeiro-Kumara et al., 2020-in this issue**), the impact of land-use change in tropical forests and their implication on soil and aquatic ecosystems (**Thomaz et al., 2020-in this issue**), modeling small watersheds (**Marin et al., 2020-in this issue**), watersheds ecological water system (**Zhao et al., 2020-in this issue**), the fate of nitrogen in stormwater (**Wen et al., 2020a-in this issue**), stormwater and wastewater nitrogen removal (**Wen et al., 2020b-in this issue**), mangrove conversion impact on carbon stock (**Eid et al., 2019-in this issue**), soil erosion (**Martínez-Murillo et al., 2020-in this issue**), bonfires effects on soil properties (**Francos et al., 2020-in this issue**) and soil adsorption antibiotics (**Conde-Cid et al., 2019-in this issue**).

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[6] https://www.unwater.org/water-facts/climate-change/

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Figures

Figure 1. Urban trails in Vilnius. Source: Google Earth

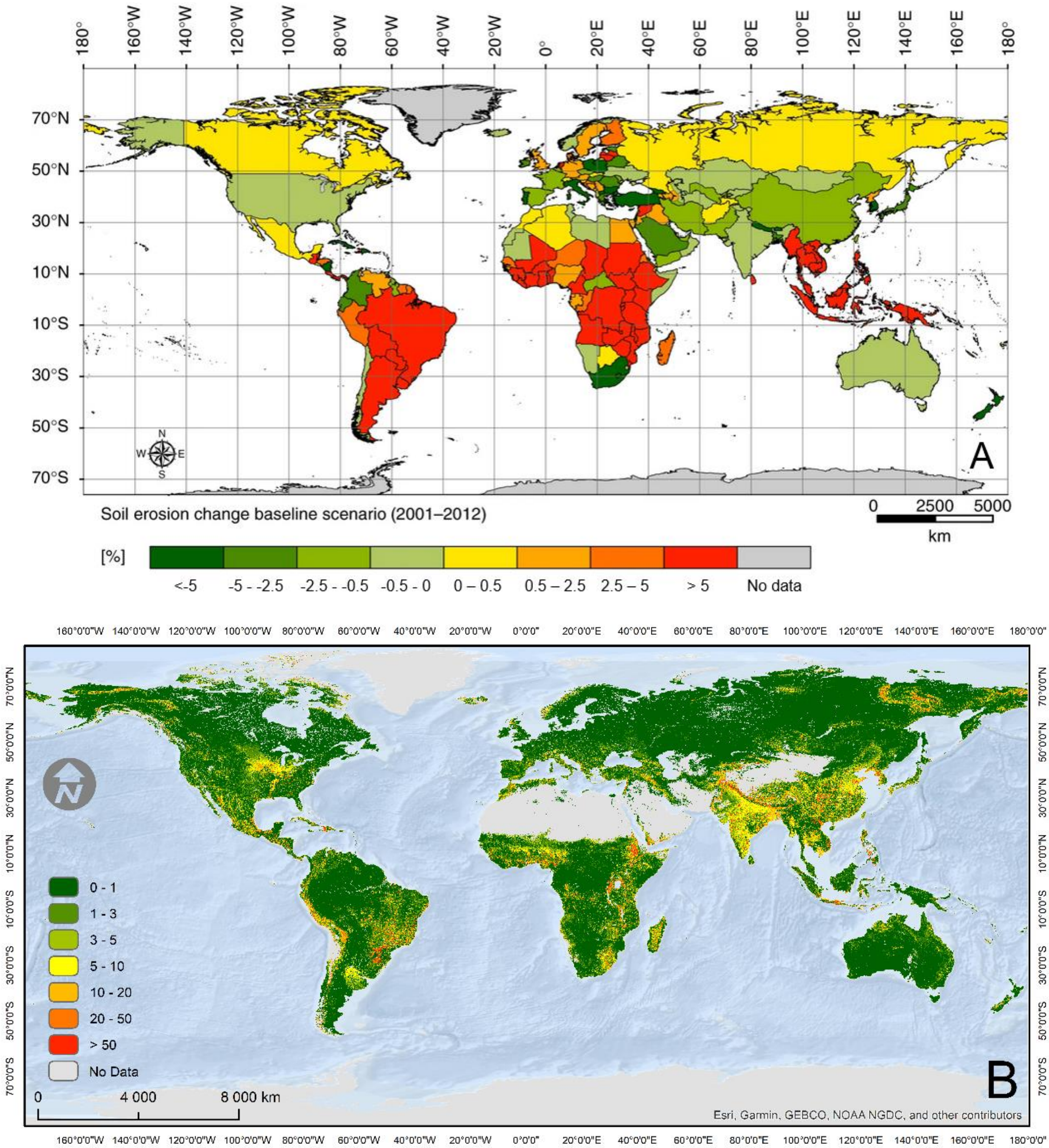

Figure 2. Diference in global soil erosion A) between 2001 and 2012 (Data in %) and B) 2012 (Data in Mg ha^{-1} yr^{-1}). Source: **Borrelli et al. (2017).**

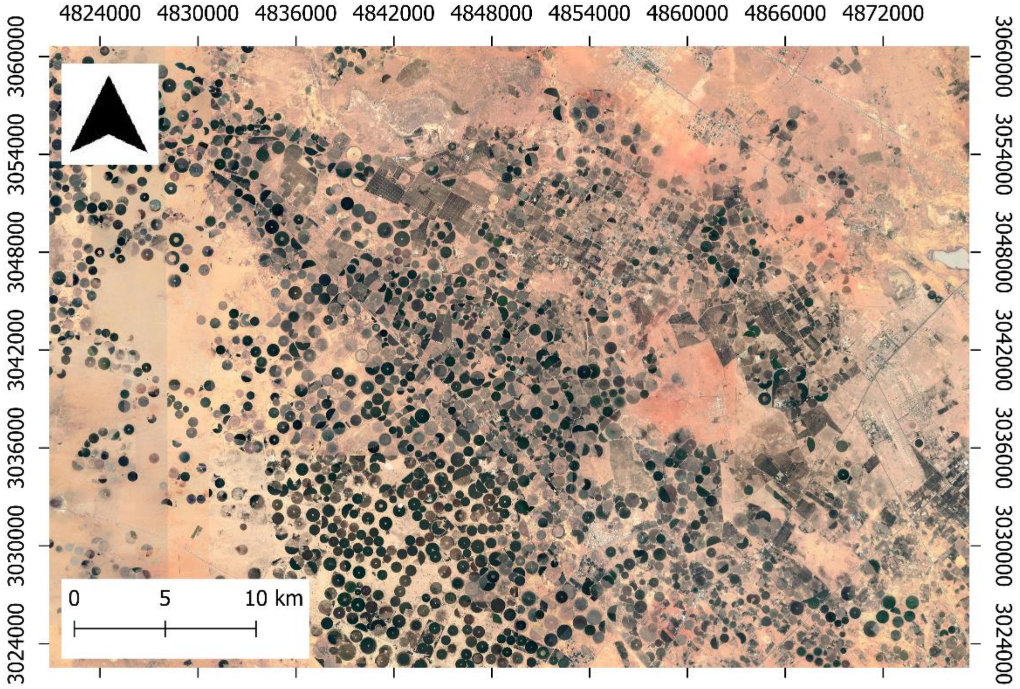

Figure 3. Intensive agriculture in Saudi Arabia desert. Some of the fields were abandoned as consequence of soil salinization and/or groundwater overexploitation. Source: Google Earth.

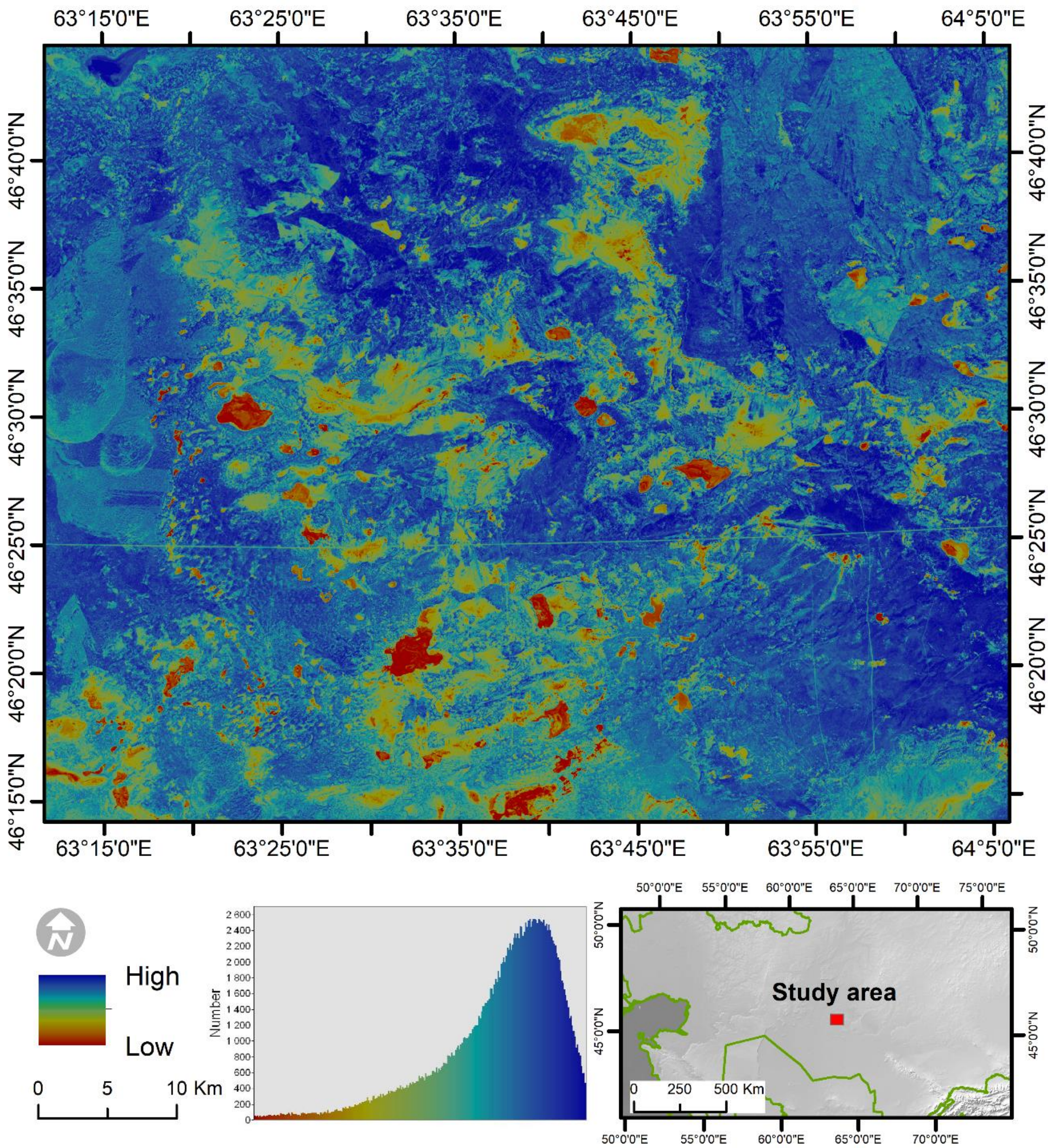

Figure 4: Soil salinization in Kazakhstan. Normalized Difference Salinity Index (NDSI) calculated from Landsat 7 image. Data source: https://earthobservatory.nasa.gov/

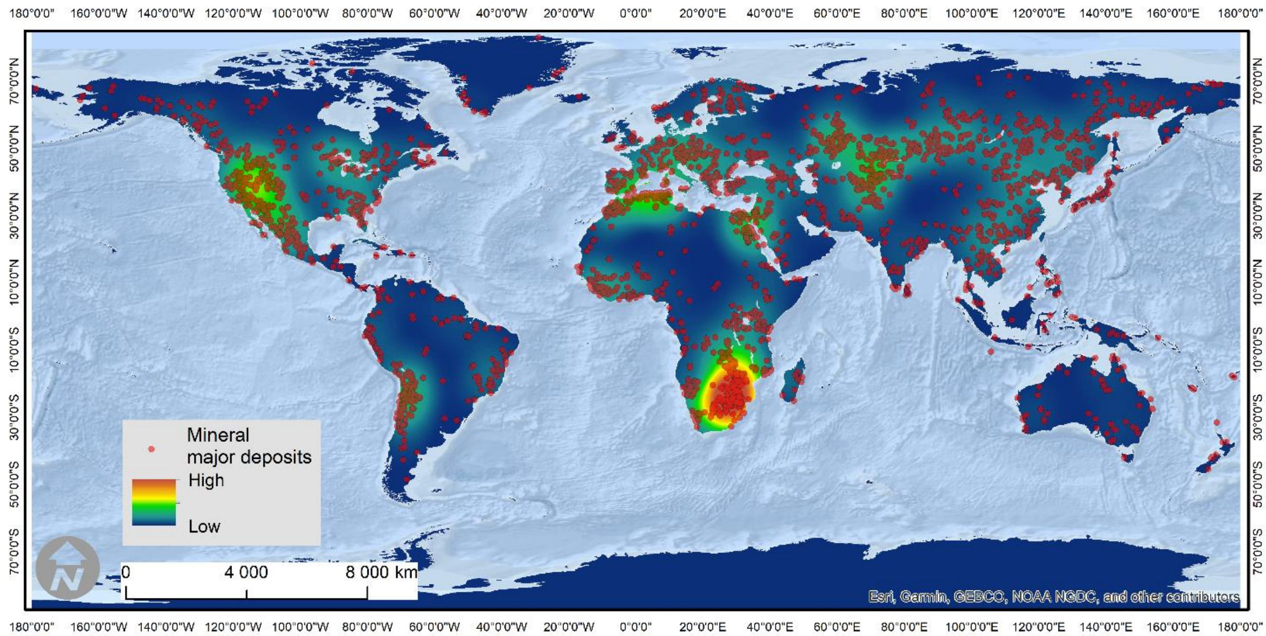

Figure 5. Mineral major deposits in the world density. Density was calculated using kernel density analysis. Data source: https://mrdata.usgs.gov/major-deposits/

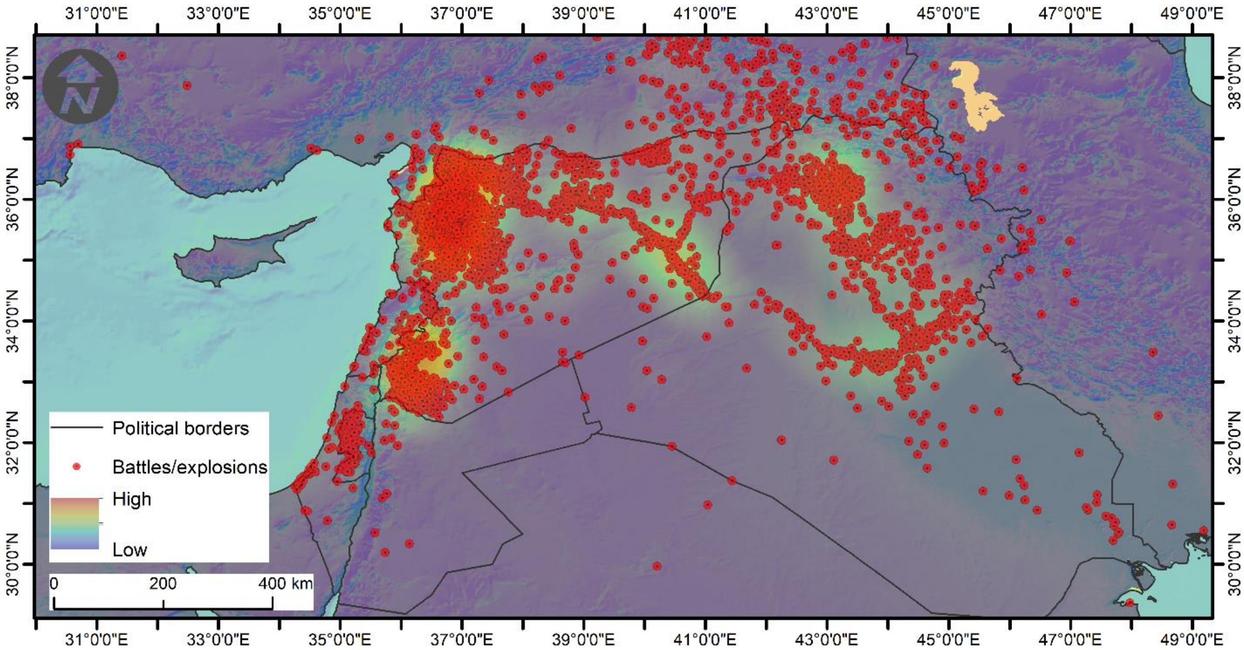

Figure 6. Areas affected by battles and explosions as consequence of war between 2015 and 2020. Density was calculated using kernel density analysis. Data source: https://acleddata.com/